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The objectives of this project are to understand the dynamics of, and to build a predictive capability for, wind-driven mesoscale oceanographic processes (2-50 km horizontal space scales, 2-10 day time scales) over the continental shelf. The project combines modeling, data assimilation and an observational program off Oregon. The observation program took place in summer 1999. It included surface current measurements from the OSU Coastal Radar System and sub-surface current measurements from three moorings deployed off Newport. Measurements of temperature, salinity, and other variables were obtained using a small, towed undulating vehicle on over 20 across-shelf sections during the summer. In addition, hydrographic, bio-optical, velocity and microstructure measurements were made throughout the water column over the shelf during a three week cruise. These hydrographic measurements give new information on the complex three-dimensional structure of the shelf circulation that results from interactions of the flow with Heceta Bank. High-resolution, three-dimensional coastal ocean circulation models were forced by buoy observed winds and heat flux and also by fluxes from a high resolution coastal atmospheric model, nested in an operational large-scale weather prediction model. New techniques to assimilate surface current measurements from land-based radars in the coastal ocean models have been developed and applied.

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FINAL TECHNICAL REPORT

ONR GRANT N00014-98-1-0787
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Title: The Prediction of Wind-Driven Coastal Circulation

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Industrial Partners: J. Svejkovsky (Ocean Imaging), D. Barrick and B. Lipa (CODAR Ocean Sensors)

The objectives of this project are to understand the dynamics of, and to build a predictive capability for, wind-driven mesoscale oceanographic processes (2-50 km horizontal space scales, 2-10 day time scales) over the continental shelf as influenced by temporal and spatial variability of the atmospheric forcing, by spatial variability of the continental margin, and by internal mixing related to small-scale turbulence. The ocean variability of interest includes the physical processes associated with energetic alongshore coastal jets, upwelling and downwelling fronts, and eddies

The project combines modeling, data assimilation and an observational program off Oregon. High-resolution, limited area three-dimensional coastal ocean circulation models are being applied to an Oregon coastal region for direct simulations, data assimilation and process studies. A regional atmospheric model is used to estimate surface forcing fields and to study the dynamics of the coastal lower atmosphere using triply nested grids. The ocean models are being forced by observed winds and heat flux and also by fluxes from the regional atmospheric model and the results compared with observations. A practical sequential data assimilation system has been developed for implementation with the ocean model.

OBSERVATIONAL PROGRAM

The observational program includes long-term measurements from the OSU Coastal Radar System presently deployed near Newport. During summer 1999, NOAA ETL partners expanded the land-based radar coverage (J. Harlan) and obtained vertical wind profiles using an upward-looking RASS profiler on the coast (J. Wilczak). Satellite-sensed sea surface temperature and roughness were made available by Ocean Imaging (J. Svejkovsky). Bi-weekly hydrographic and zooplankton sampling was conducted off

Newport by NOAA NMFS (W. Peterson). CODAR Ocean Sensors (D. Barrick, B. Lipa) worked on testing the feasibility of improving the direction-finding capabilities of their standard SeaSonde antenna.

Additional measurements by OSU PIs included observations of temperature, salinity, chlorophyll, fluorescence and light transmission from over 20 cross-shelf sections off Newport obtained using a small towed, undulating vehicle (MiniBAT). During May to August 1999, three moorings equipped with current, temperature and conductivity sensors were deployed off Newport. One of the moorings measured atmospheric variables. Moored observations are being used to study the response of the coastal ocean to wind forcing and to verify the numerical ocean models.

A three-week cruise aboard the *R/V Wecoma* was made during July 1999. High-resolution hydrographic, bio-optical, velocity and microstructure data throughout the water column were collected in a region near Newport. The hydrographic and velocity fields are being used to initialize and provide data for assimilation into the coastal model. Over 12,000 CTD profiles obtained using the towed vehicle SeaSoar have been used to form vertical sections and horizontal maps which, when combined with shipboard ADCP velocity measurements, are being used to investigate mesoscale dynamics. Measurements of the Inherent Optical Properties (IOP) are being used to estimate chlorophyll, sediment, and colored dissolved organic concentrations and to relate their distributions to physical features (upwelling front, submarine banks, Columbia River plume, etc.) and to SeaWiFS imagery.

The microstructure data are being used with the model to assess the role of small scale turbulence in determining the mesoscale structure of the flow and hydrographic fields. Over 1300 profiles of turbulence parameters and light backscatter are being used to estimate bottom stress and to investigate details of the bottom boundary layer over the shelf.

A measure of upwelling intensity based on cross-shelf vertical sections obtained through the upwelling season off Newport was developed. This measure was found to be highly correlated with an upwelling index formed by taking an exponentially weighted running mean of the alongshore wind stress. This relationship can be used to predict when subsurface waters will be exposed at the sea surface (Austin and Barth, 2001).

The 3D SeaSoar hydrographic surveys show that the wind-forced, southward coastal upwelling jet follows the Heceta Bank topography as it widens offshore. The jet reaches the southern end of the Bank, where the shelfbreak turns almost 90 degrees back toward the coast. This flow-topography interaction creates pressure gradients that, following wind relaxations, drive flow back to the north. This leads to northward flow on the inshore side of the Bank and even recirculation around the entire Bank system. Sections across the shelf upstream and downstream of a midshelf submarine bank demonstrate the role of bottom topography in directing the alongshelf upwelling jet offshore and mixing the overlying water column. Each of these processes, recirculation, offshore flux of shelf water and mixing, has a significant influence on coastal ocean ecosystem dynamics.

MODELING AND DATA ASSIMILATION

Atmospheric forecasts were made regularly with a regional, high-resolution atmospheric model, the Univ. of Oklahoma's Advanced Regional Prediction System (ARPS). This nonhydrostatic, mesoscale atmospheric model was initialized and forced with the National Center for Environmental Prediction (NCEP) Eta model operational forecast and analysis. Model forecasts and forecast statistics were compared with meteorological observations including moored and coastal surface meteorological stations and RASS profiler data.

Comparison of atmospheric model results with observations suggests that the model performed sufficiently well to provide useful estimates of wind stress in regions where wind measurements were not available (Samelson et al., 2001). Both the mean and variable components of model alongshore wind stress increase by factors of 3-4 from north to south along the Oregon coast. There is evidence of orographic intensification near Cape Blanco, which is supported by previous aircraft and ship observations during August 1995. Differences between model and buoy surface air temperatures are highly correlated at 16-18 hour lag with southward stress, and evidently arise because the atmospheric model sea surface temperature analysis does not resolve the cold upwelled water near the coast. This suggests that ocean upwelling modifies coastal surface air temperatures by 1-5° C over time scales of 12-24 hours. The low-level atmospheric jet undergoes diurnal horizontal and vertical displacements that are in some ways similar to what has been observed and modeled along the California coast (Bielli et al., 2001). There is also a minimum in northerly wind between 1500 and 1800 UTC (0700 and 1000 local time) and a double maximum of offshore flow above the marine boundary layer. The advection of alongshore wind is an important term in the alongshore force balance. Thus, in contrast to the previous results for the California coast, the diurnal circulation is fundamentally three-dimensional in the coastal zone and as far as 100 km offshore.

High-resolution, three-dimensional coastal ocean circulation models utilizing the Princeton Ocean Model (POM) are being applied to an Oregon coastal region for direct simulations, data assimilation and process studies. Two model configurations are used. Both have limited-area, high-resolution grids with realistic Oregon coastal topography. The first configuration extends 600 km alongshore, from 41.7°N to 47°N, and 250 km offshore and contains three open boundaries. The second configuration is of similar size, but involves idealized periodic boundary conditions at the northern and southern boundaries. The ocean models are being forced by observed winds and heat flux and the results compared with observations. The limited-area, open-boundary circulation ocean model is also being driven by fluxes from the regional atmospheric model. The sensitivity of model-produced upwelling circulation to turbulent closure schemes is being investigated. The Mellor-Yamada level 2.5 scheme, the k-epsilon closure, and the K-Profile Parameterization (KPP) are being utilized. The structure and strength of the resulting vertical mixing is studied and compared. In addition, the effects of the different schemes on the mesoscale circulation are assessed.

A practical, sub-optimal, sequential data assimilation system has been developed for implementation with POM (Oke et al., 2001a). Inhomogeneous and anisotropic estimates of forecast error covariances, used to project information from the surface current measurements onto the full three-dimensional model grid, are obtained by assuming that the forecast error

covariances are stationary and are proportional to the "typical" cross-correlations between modeled variables. The forecast error covariance fields for the data assimilation system were calculated from an ensemble of 17 model runs where the model was forced with observed winds from 17 different "typical" summers (July and August) between 1969 and 1998 A time-distributed averaging procedure was developed in order to overcome difficulties with primitive equation initialization and assimilation of low-pass filtered data into a model admitting fluctuations at all frequencies

The effectiveness of the assimilation system has been demonstrated by assimilating HF-radar derived surface currents into POM and comparing the analyzed sub-surface velocities over the mid-shelf to independent observations during summer 1998 (Oke et al., 2001a). The correlation coefficient of the modeled depth-averaged velocities without assimilation is 0.42 and with assimilation is 0.76. This significant improvement demonstrates the potential of the assimilation system. The analysis of the modeled dynamical balances indicates that the primary source of model error is uncertainties in the spatial details of the applied wind stress. Applications of the data assimilation system for summer 1999 are in progress.

The limited-area, periodic POM was configured for the sub-inertial continental shelf circulation for summer 1999 off Oregon. A series of numerical experiments were performed investigating the models sensitivity to wind forcing, surface heating, model domain size and initial conditions. The model results were compared with in situ velocity, temperature and salinity measurements obtained during the 1999 intensive OSU NOPP field season. Comparisons were made with measurements from moored instruments, MiniBAT surveys, SeaSoar surveys and shipboard ADCP transects. In general, the model results are in good agreement with observations on the shelf. The magnitude of the complex cross-correlation between observed and modeled currents are approximately 0.8 over the inner shelf and 0.5 over the mid-shelf (Oke et al., 2001b).

The limited-area, open boundary POM was forced both by buoy measured winds assumed spatially uniform and by spatially variable wind stress fields from the mesoscale atmospheric model. The model results were compared with the moored current measurements. Initial results showed improved agreement of modeled and observed velocities with forcing by the spatially variable winds from the mesoscale atmospheric model compared with forcing by spatially uniform buoy winds (Gan and Allen, 2001).

The effects of different turbulent parameterization schemes were examined in both two-dimensional (alongshore uniform) and three-dimensional numerical experiment. Results show that substantial differences in model-predicted vertical mixing may exist and that they occur primarily in the upwelling frontal region and in the bottom boundary layer. The reasons for these differences and their implications for the mesoscale flow are being investigated (Wijesekera, Allen and Newberger, 2001).

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